

Transparent Spinel Ceramic

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Spinel Ceramic: Spinel (MgAl_2O_4) is a cubic crystalline material with a unique combination of ruggedness and excellent transmission from the ultra-violet ($0.2\ \mu\text{m}$) to the mid-infrared ($5\ \mu\text{m}$) region. This positions spinel as the de facto material of choice for numerous Department of Defense and commercial infrared window applications. However, single crystal spinel is difficult to make in dimensions greater than a few millimeters using traditional high temperature ($>2000\ ^\circ\text{C}$) melt growth techniques. On the other hand, attempts to make polycrystalline spinel by traditional hot pressing of powder has led to inhomogeneous material, typified by opaque nontransmitting regions, thereby making it unsuitable for practical applications. However, NRL has solved this problem.

NRL's Technology: We have identified that the poor quality of commercial spinel ceramic is attributed to the inhomogeneous mixing of the sintering aid (LiF) with the spinel powder. This leads to porosity and trapped sintering aid. Therefore, we have developed a novel and patented process to uniformly coat the sintering aid onto every spinel powder particle and enable its removal during the hot-pressing process at around $1600\ ^\circ\text{C}$.¹ This enables full densification and fabrication of uniformly transparent high-optical-quality spinel ceramic. The process is scalable to make large windows, but also by designing suitable hot-press molds, it is possible to make thick windows and conformal optics including lenses and dome shapes (Figs. 4 and 5).

Applications: The availability of high-optical-quality spinel ceramic in different shapes and sizes makes it an excellent window material for many applications. Some of the applications being pursued for spinel are described in the following paragraphs.

DDG 1000. The DDG 1000 destroyer (Fig. 6) requires high-strength, large-sized windows for the bridge that exhibit both visible and infrared transmission to $5\ \mu\text{m}$ and must withstand up to 8 psi waveslap. Since NRL's hot-press process is scalable to large sizes, the bridge window could be made from one large piece of spinel, or alternatively it could be made by edge diffusion bonding of two or more smaller windows together. The feasibility of both of these approaches has been demonstrated (Fig. 4).

Photonic Mast for Virginia Class Submarines.

Existing windows on the mast use silica glass and crystalline germanium for transmission of visible and mid-infrared light, respectively (Fig. 6). Unfortunately, both materials are weak and prone to damage, despite the fact that they are 1.5 in. thick. The replacement of both windows with a single window of spinel will enhance survivability and significantly reduce maintenance and life cycle costs. The challenge is how to make thick spinel windows. By refining the hot-press process, we have successfully demonstrated preparation of 1.5-in. thick spinel ceramic with very good optical quality (Fig. 5).

High Energy Lasers. High energy lasers (HEL) are being developed for directed energy weapons systems, but the exit aperture (i.e., window) has been identified as the single point of failure due to a combination of poor thermal, optical, and mechanical properties (Fig. 6). This is especially true for glass windows since they possess very low thermal conductivity, which leads to thermal shock. Their low strength also makes them unsuitable for applications in hostile environments. On



FIGURE 4

A 12-in. x 16-in. x 0.5-in. single pane of spinel ceramic and a 6-in. x 3-in. x 0.5-in. part made by edge diffusion bonding two smaller pieces.



FIGURE 5
Examples of a thick (1.5-in.) spinel window and a dome.

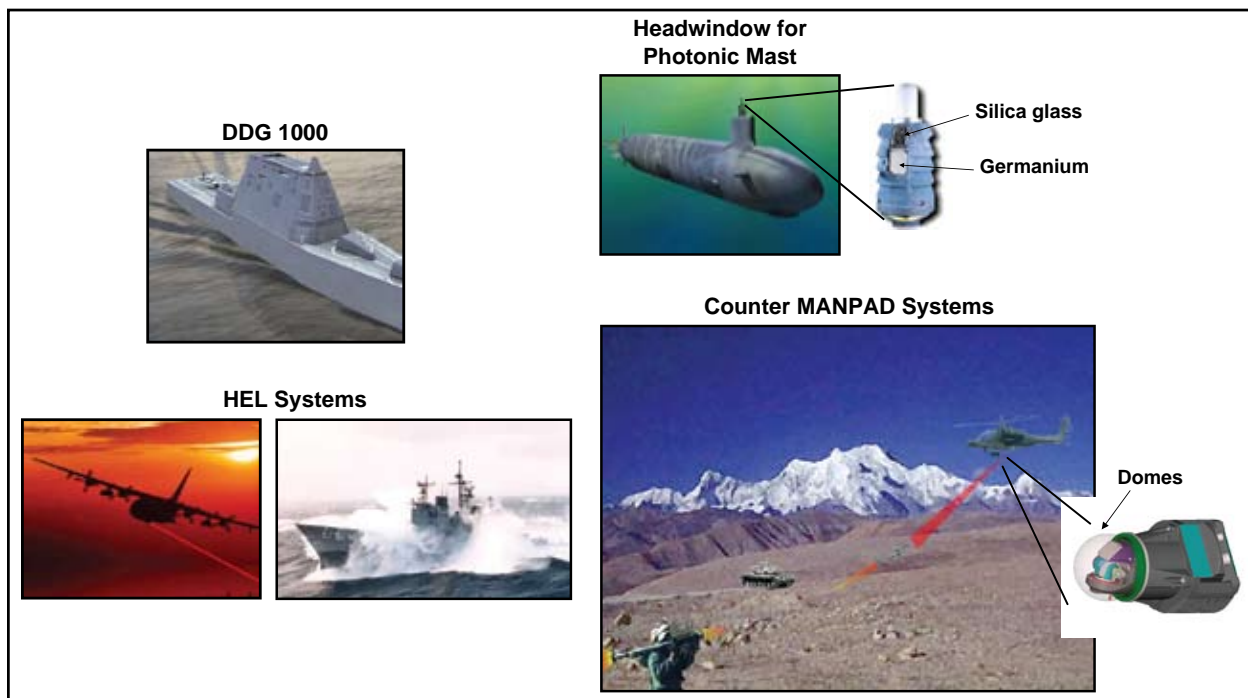


FIGURE 6
Several applications that will benefit from development of transparent spinel ceramic.

the other hand, spinel's excellent ruggedness enables its use in hostile environments and its higher strength enables the use of thinner windows, thereby reducing weight. NRL has developed technology to make ultra-high-purity spinel powder, which has been used to make spinel ceramic with a record low absorption loss of 6 ppm/cm at $1.06\ \mu\text{m}$. A combination of low absorption loss and high strength lead to very low optical path distortion of the laser beam.

Domes for Missile Protection Systems. Rugged infrared transmitting domes are needed in systems to counter Man-Portable Air Defense Systems (MANPADS) and provide platform and personnel protection against infrared seeking missiles (Fig. 6). Existing materials, such as crystalline silicon, are weak and also do not provide visible transmission, while sapphire

provides limited transmission at a wavelength of $5\ \mu\text{m}$. However, spinel provides both visible transmission and better transmission than sapphire at $5\ \mu\text{m}$, and without compromising the mechanical performance. Consequently, we have modified the hot-press die design and process and successfully demonstrated fabrication of spinel domes (Fig. 5).

In addition to the applications described above, the availability of high-optical-quality spinel ceramic with high strength will also enable fabrication of lightweight blast shields, face shields, and goggles for personnel protection from improvised explosive devices (IEDs) as well as conformal windows for reconnaissance. NRL's spinel technology has been licensed to industry and the "Transparent Spinel Ceramic" technology was selected as the winner of the 2008 National Award for Excel-

lence in Technology Transfer by the Federal Laboratories Consortium.

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Reference

¹G. Villalobos, J.S. Sanghera, S.B. Bayya, and I.D. Aggarwal, "Fluoride Salt Coated Magnesium Aluminate," U.S. Patent 7,211,325, May 1, 2007.